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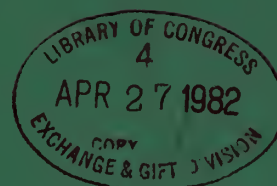
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Borehole Shear Tester: Equipment and Technique

By Khamis Y. Haramy



UNITED STATES DEPARTMENT OF THE INTERIOR

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UNITED STATES DEPARTMENT OF THE INTERIOR

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BOREHOLE SHEAR TESTER: EQUIPMENT AND TECHNIQUE

By Khamis Y. Haramy¹

ABSTRACT

This Bureau of Mines paper describes the use of the borehole shear tester (BST) in mines. Assembly and procedure sections explain how the equipment is assembled and used properly. Schematics of the BST, limitations, test hole specifications, data recording, and calculations are all explained briefly, and an example of the data collecting and calculations is given to assist understanding.

INTRODUCTION

The borehole shear tester (BST) was developed by Dr. Richard L. Handy of Iowa State University in 1976 under Bureau of Mines Contract G0144021. The purpose of the work was to obtain a device for rapid, in situ measurement of rock shearing strength as a function of the normal stress acting on the plane of failure. The device is light in weight, mechanically simple, and easily transported. It is sufficiently durable to withstand repeated use in adverse environmental conditions and can be used in the rib, roof, or floor of the mine. It requires an NX-size borehole.

The data obtained from BST tests support well-known theories such as Mohr's theory of failure. This theory is based on a relationship between shearing stresses and normal stress at every point within the specimen body. The Coloumb theory, which is considered to be a special case of Mohr's theory, and the 1921 Griffith theory, which deals with material failure on a microscopic basis, are also supported by the BST results.

Owing to the difficulty in obtaining large samples of coal and rock for laboratory testing and the bias that is introduced in large samples, the borehole shear tester promises to be of significant value to the mining engineer and researcher in determining physical properties of in situ rock formations.

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USING THE BOREHOLE SHEAR TESTER

The BST is a device for making in situ tests to determine the shear strength of coal and rock using a 76-mm-diameter borehole (NX-size) up to 12 m long determines the shear strength as a function of the normal stress acting on a plane of failure.

LIMITATIONS

1. Do not use the BST in unsupported roof rock or within 1 foot of the borehole collar because it may cause spalling and buckling.
2. Do not exceed a shearing stress of 6,500 psig.
3. Do not fully extend the shear plates unless the BST body is in place inside the borehole.
4. Use the right type of shear plates depending on the type of rock tested, as described in table 1.

TABLE 1.—Types of shear plates available for various rock types

Type designation	Configuration	Tooth spacing, inch	Number of teeth	Tooth depth, inch	Shear area per plate, sq in	Remarks
Steel...	Flat full wedge.	0.4	3	0.040	0.8	Used for softer rocks only.
Carbide insert.	.. do ..	.8	2	.040	.7	Used for coal and all other rocks. ¹

¹The upper limit of rock strength has not been decided. However, the device has been used in hard rock such as granite.

TEST HOLE SPECIFICATIONS

1. Diameter of test hole should be 76 mm (NX-size).
2. Length of test hole should not be less than 1 meter.
3. Hole should be dry to prevent rock dust penetrating behind the shear plates and thus preventing their free rotation. If water exists, the shear head swivel should be covered with a heavy grease.
4. Hole must be freshly drilled and clear of dust and cuttings, especially in rapidly deteriorating material such as coal and shale.
5. Drilling may be done by diamond bit, pneumatic percussion drill, or others, provided the borehole is smooth, straight, and free of ridges.

BST COMPONENTS

The unassembled BST components are shown in figure 1.

Shear Head (fig. 2)

1. Two shear plates, each with two or three teeth which penetrate into the rock when normal pressure is applied, are mounted at the end of a double-acting hydraulic cylinder. The plates are fixed in place and linked to individual push plates, which apply the normal force. Two types of shear plates are available for use with different ranges of rock strength (table 1). The steel plates are adequate for coal and softer rocks. If the teeth chip or wear, the carbide insert shoes should be used.

2. The two push plates are connected to a locking mechanism and stay parallel during initial shear head expansion.

3. Two short hydraulic hoses of different lengths are provided, which connect onto the BST body. One is used for shear plates expansion, the other for retraction.

Pulling Assembly (fig. 3)

1. A 12-ton center hole, hydraulic jack fits over the threaded pull rod for pulling.

2. An adjustable tripod is used to assure axial alignment of jack and threaded rod.

3. Jack base plate.

4. A lock grip half-nut clamp provides a quick-acting stop nut on the threaded rod.

5. A dial gage reads displacement of BST in the hole, if required.

Console (fig. 4)

1. Hand pump.

2. Lever-type pump valve for "open-close" operating modes.

3. Normal pressure valve and gage to read the applied pressure for normal forces against the shear plates.

4. Shear pressure valve and gage to read the applied pressure for shearing forces between the shear plates and the rock.

5. Manifold valve (expand-neutral-retract) used for the expansion and retraction of the shear plates.

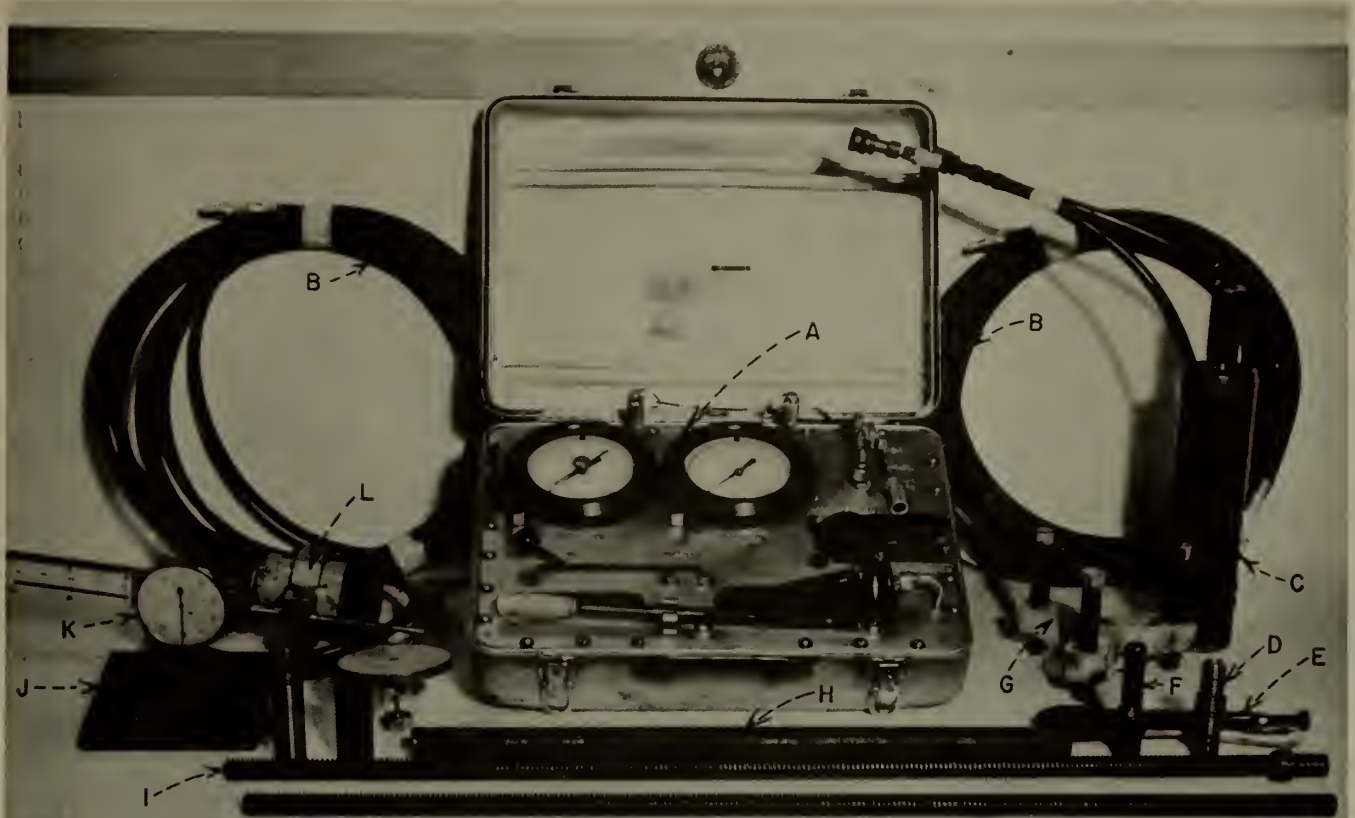
6. Three hydraulic ports (shear, retract, and normal) onto which the hydraulic hoses connect.

7. Two unmarked terminals for possible addition of shear and normal pressure transducers. (Otherwise these are left capped.)

8. An aluminum case to protect the console.

Miscellaneous

Other BST assembly components include hydraulic extension lines, threaded rods, RW adapters, and RW-size rods in 5-foot sections. Figure 5 shows a schematic of the BST and the way it should appear when placed in the hole.



- | | |
|--------------------------|----------------------|
| A. Console | G. Adjustable tripod |
| B. Hydraulic hoses | H. RW rod |
| C. Shear head (BST body) | I. Threaded rod |
| D. RW rod connector | J. Jack base plate |
| E. Half-nut clamp | K. Dial gage |
| F. RW rod adapters | L. Hollow jack |

FIGURE 1.—Borehole shear tester components.

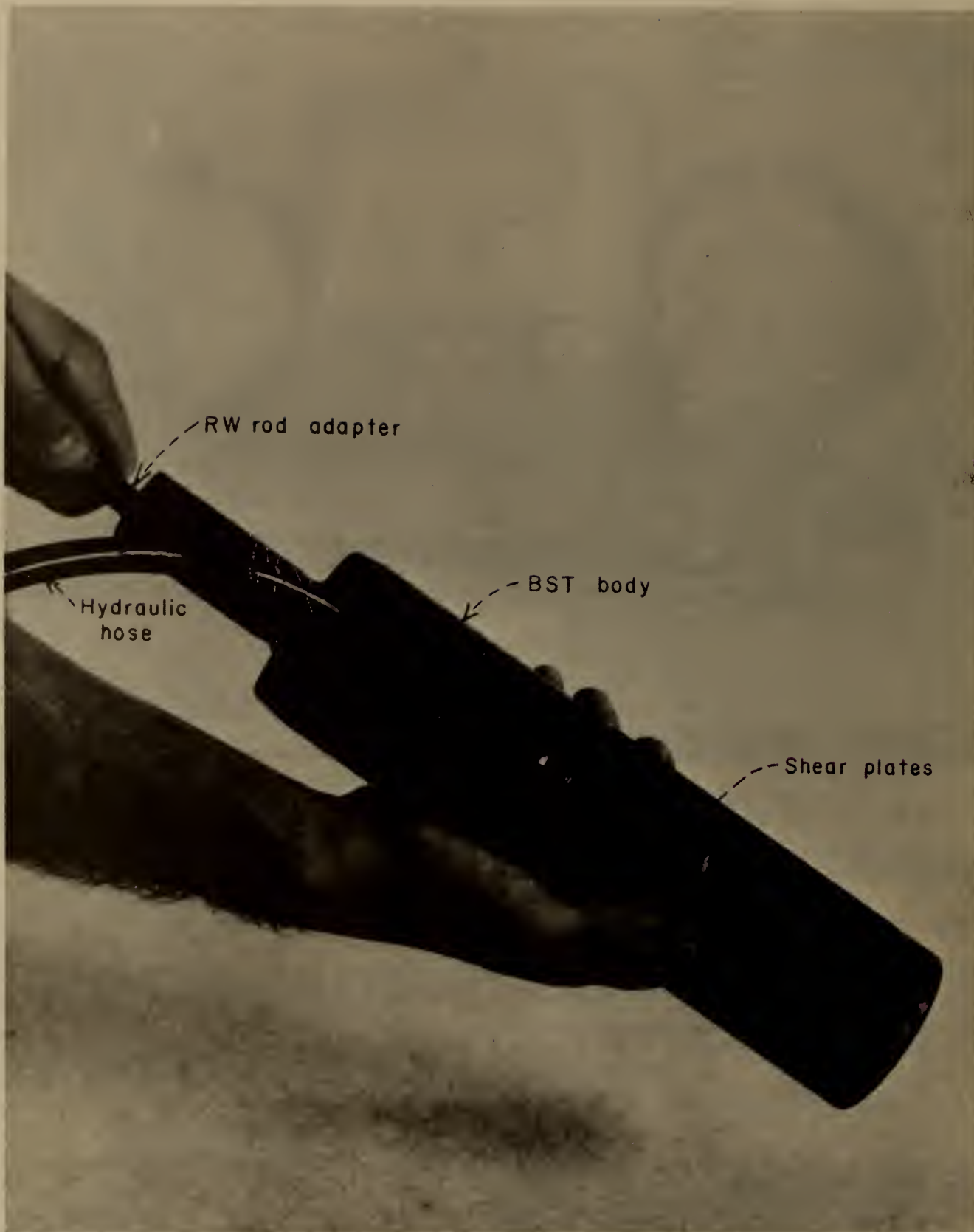


FIGURE 2.—Closeup view of the borehole shear tester head.

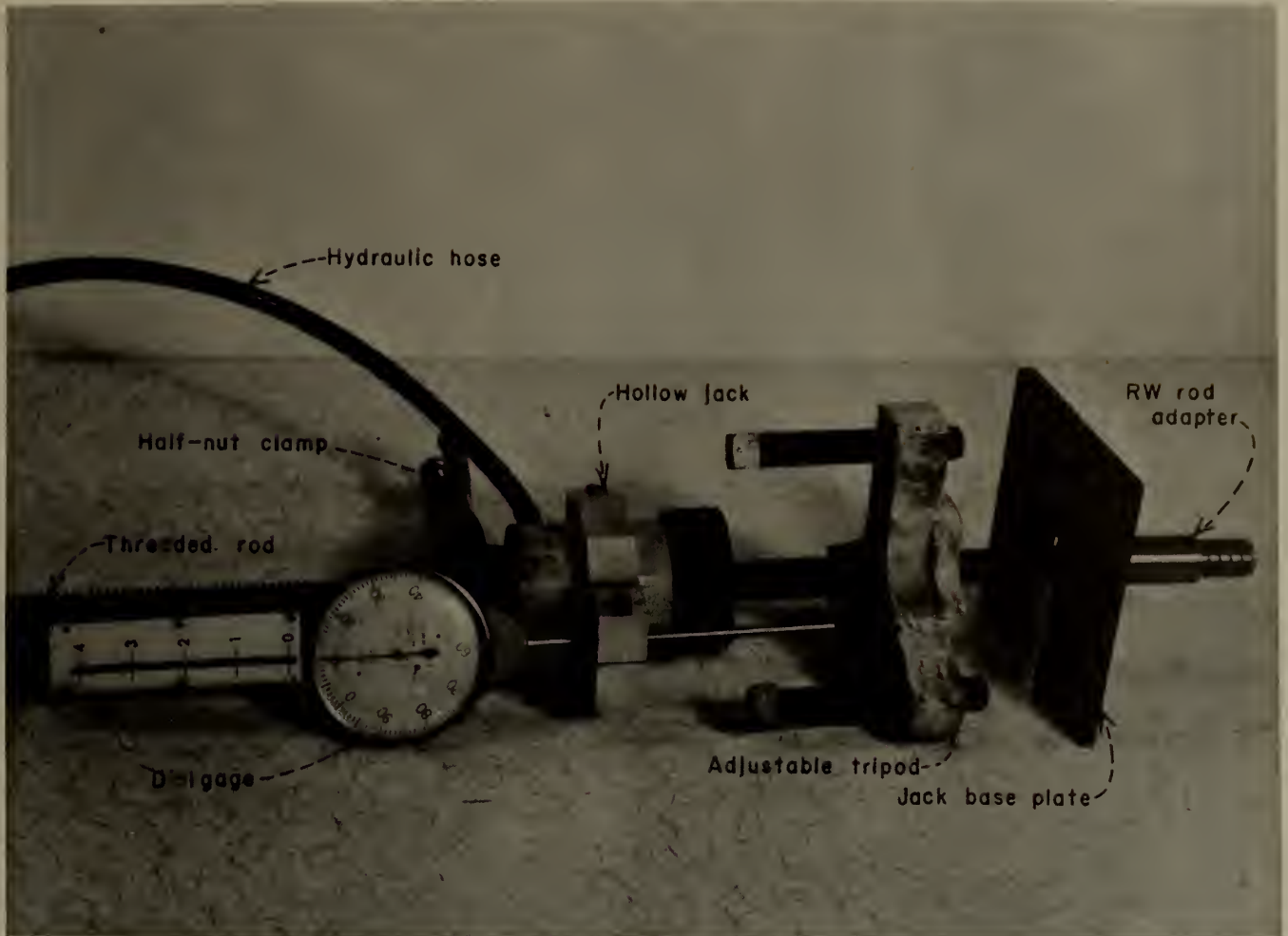


FIGURE 3.—Pulling assembly including hollow jack, half-nut, clamp and dial gage.

- A. Aluminum case
- B. Hydraulic ports
- C. Manifold valve
- D. Hand pump
- E. Pump valve
- F. Normal pressure valve and gage
- G. Shear pressure valve and gage
- H. Unmarked terminals

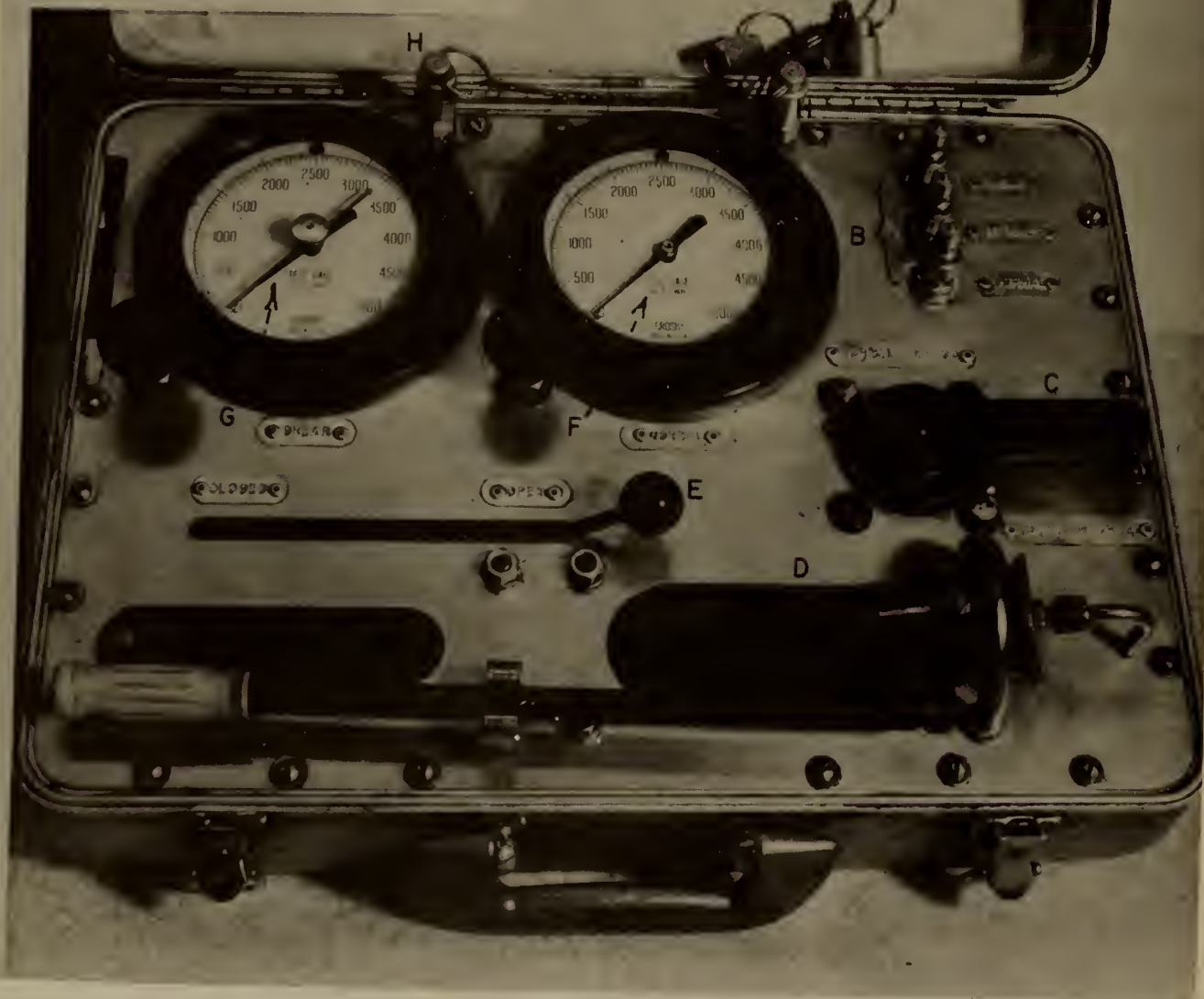


FIGURE 4.—Closeup view of the console.

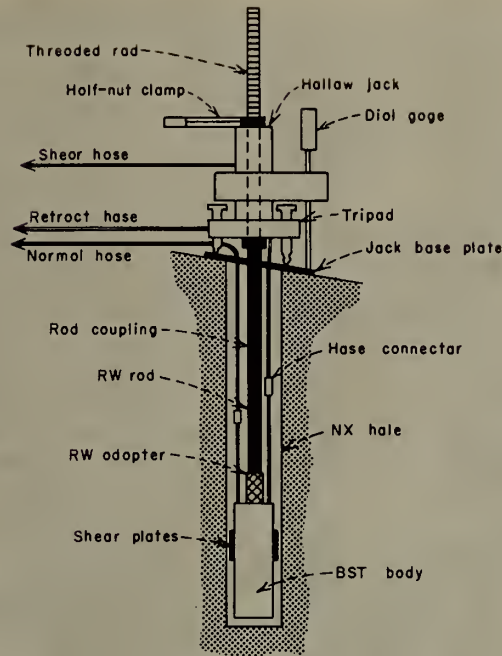


FIGURE 5.—Schematic of the BST in the hole.

BST ASSEMBLY

In assembling the borehole shear tester, refer to the sequence of photographs 6 through 17 to help understand each step in the process. At least a 12-inch pipe wrench, several screwdrivers, an 8-inch crescent wrench, shear plates, and hydraulic fluid are tools needed for the BST setup.

1. Screw the RW rod adapter into the end of the BST body. This adapter adapts the thread in the BST body to the RW rod thread (fig. 6).

2. Couple the hydraulic extension hoses to the hoses attached to the BST body (fig. 7).

3. Mark the extension hose that is connected to the shorter hose from the BST body (fig. 8). (The BST has a long hose section and a short hose section attached to it.)

4. Attach the RW rods in 5-foot sections to the rod adapter (fig. 8).

5. Place the BST body in the hole with the shear plates at a known orientation, such as N-S or E-W, and a known depth (fig. 9). Record both orientation and depth on the data sheet.

6. When the BST body is at the required depth, attach another RW adapter, to the RW rod (fig. 9). The reason RW rods are used is that they are much stiffer than threaded rods, which eliminates bending or stretching while the BST is under shearing load.

7. Screw in a 3-foot threaded bar to the RW adapter attached to the end of the RW drill rod (fig. 10).

8. Mount the pulling assembly at the hole collar as follows:

a. Place the jack base plate over the threaded bar and the hoses at the collar of the hole. Allow the hoses and the threaded bar to pass through the slot in the plate (fig. 11).

b. Place the tripod with the adjustable screws against the jack base plate (fig. 12). These screws are used to align the jack along the centerline of the hole.

c. Slide the hollow jack over the threaded bar and against the tripod (fig. 13). Hold it in place, and after pushing everything tight together, secure the visegrip-type, half-nut clamp on the threaded bar tight behind the jack (fig. 14). The pulling assembly should look like figure 15 before testing begins. The dial gage, shown in figures 13-16, is included in the assembly only if axial displacements of the BST are to be measured, see "Procedure" section.

Caution:—If the testing is in a vertical hole, the BST pulling rods and tripod assembly should be held in the center of the hole at the collar at all times until the normal seating pressure is applied. It is recommended that, for safety purposes, a safety chain and rod hook be used to hold the assembly in the vertical hole (fig. 16).

9. Connect the hydraulic hoses to connectors, which are in the upper right-hand corner of the console (fig. 17), as follows:

a. The marked hose (from step 3 of this section) to the port on console marked Normal.

b. The other hose from the BST body to the port on console marked Retract.

c. The hose from the jack to the port on console marked Shear.

PROCEDURE

The following procedure is for the BST in a vertical upward hole. In a downward vertical hole, the procedure is similar, except that when placing the BST body in the borehole, one should restrain it or it may be lost in the hole. Remember to record the orientation and depth of the shear plates before every test.

1. Assemble the BST body, snap hoses on, connect rods, and place it in the hole as mentioned in the previous section, steps 1 through 7 and steps 9a and 9b.

2. Place the pump valve and the valve labeled "shear" on CLOSE.

3. Open the *normal* valve, and place the *manifold* valve on NORMAL EXPAND.

4. Pump up normal gage pressure to a certain level which depends on rock type as follows:

400 psig. . . Soft rock.
1,600 psig. . . Medium rock.
3,200 psig. . . Hard rock.

Enough seating pressure must be exerted to achieve full penetration of the teeth into the rock or coal prior to the test, to insure that the teeth will shear off a coupon of rock or coal and not simply scrape the surface. Excessive displacement during the test or low apparent shear strength may indicate the need to apply a higher seating pressure. The seating pressures given above are typical and may be used as a guide. The appendix gives more details on seating pressure calculations.

5. CLOSE *normal* valve.

6. Wait 5 minutes for the teeth on the shear head to penetrate into the rock. Remember to keep holding the BST in the hole until normal pressure is applied.

7. Mount pulling assembly at the borehole collar as explained in steps 8a through 8c in the previous section.

8. Snap on the jack hose according to step 9c.

9. Adjust the dial gage for a zero reading and record it on the data sheet if BST axial displacements are to be made.

10. OPEN *normal* valve.

11. Readjust normal pressure to the chosen setting pressure (if any change in pressure has occurred) by either

pumping (to increase pressure) or opening *pump* valve slowly (to reduce pressure).

12. CLOSE *normal* valve.

13. OPEN *shear* valve.

14. Pump at a slow rate until shear gage reads 100 psig, then record the following data on the data sheet (see example in appendix):

Normal pressure . . . From normal gage on console.
Shear pressure . . . From shear gage on console.
Displacement From dial gage if desired.

15. Pump the shear pressure in steps to 200 psig, 400 psig, 600 psig, and so on until the peak shear has been determined. Record shear pressure and displacement for each pressure. If the pulling rod bends as the shear pressure is increased, the load should be released and the tripod adjusted so that the pulling action is parallel to the axis of the hole; otherwise the displacement measurements will be meaningless and the pulling rods may be damaged.

16. Continue to pump until shearing pressure changes are relatively slow or a predetermined maximum displacement is reached.

17. Upon each completion of each test, OPEN *pump* valve, CLOSE *shear* valve, OPEN *normal* valve, and switch *manifold* valve to retract.

18. Before removing BST from hole, CLOSE *pump* valve, CLOSE *shear* valve, keep *normal* valve OPEN, and pump until the shear plates retract and the BST head apparatus pulls loose from the hole.

19. For the next sequential test, reinsert the device in the hole either rotated 45° at the same depth, or at a different depth. Repeat all above procedures.

Note.—When the BST is used in harder rocks, the shear plate teeth may wear enough during a series of tests to begin to affect the results. The effect of this wear should be distributed over the length of a test hole by randomizing the depths and orientations of the shear tests.

CLEANING THE BST

After every test, clean off shear plates and make sure they swivel freely. After the completion of all testing, clean the BST body very well and lubricate it by using a WD-40 lubricant spray (or equivalent) to prevent rusting.



FIGURE 6.—BST assembly, step 1.



FIGURE 7.—BST assembly, step 2.

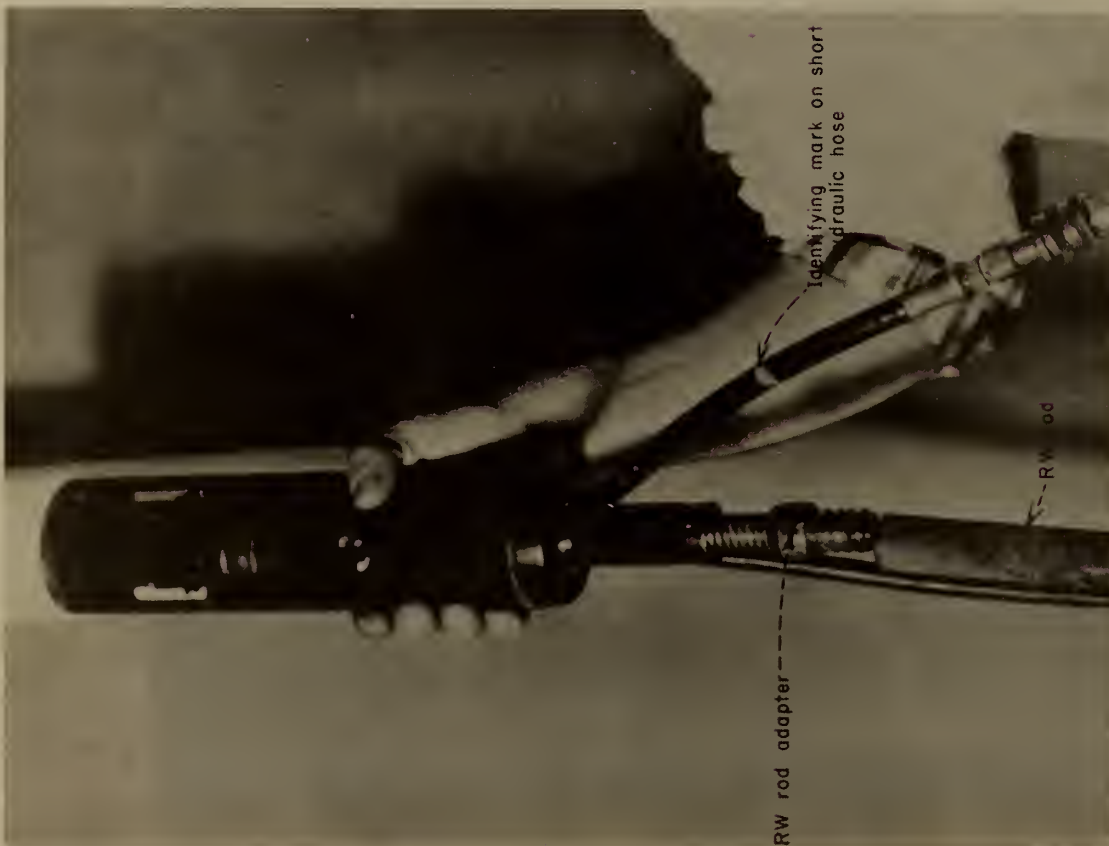


FIGURE 8.—BST assembly, steps 3 and 4.



FIGURE 9.—BST assembly, steps 5 and 6.



FIGURE 10.—BST assembly, step 7.

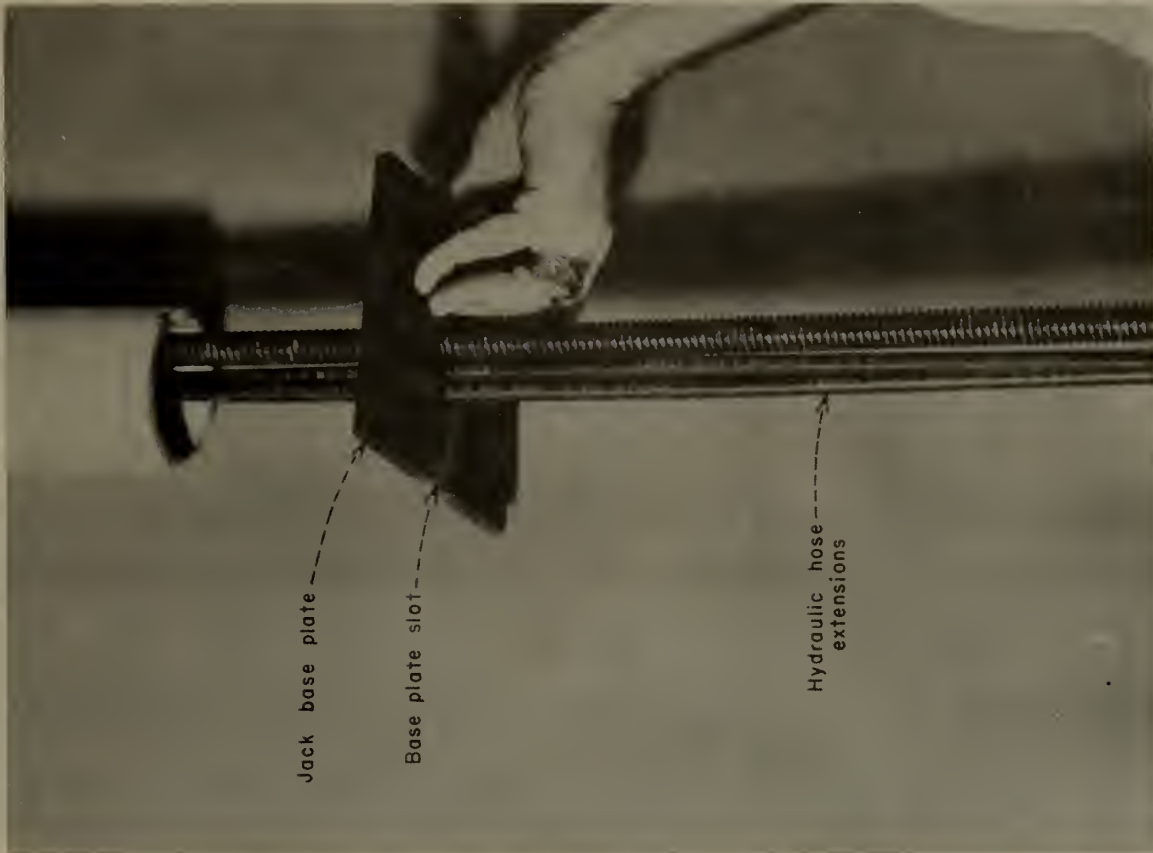


FIGURE 11.—BST assembly, step 8a.

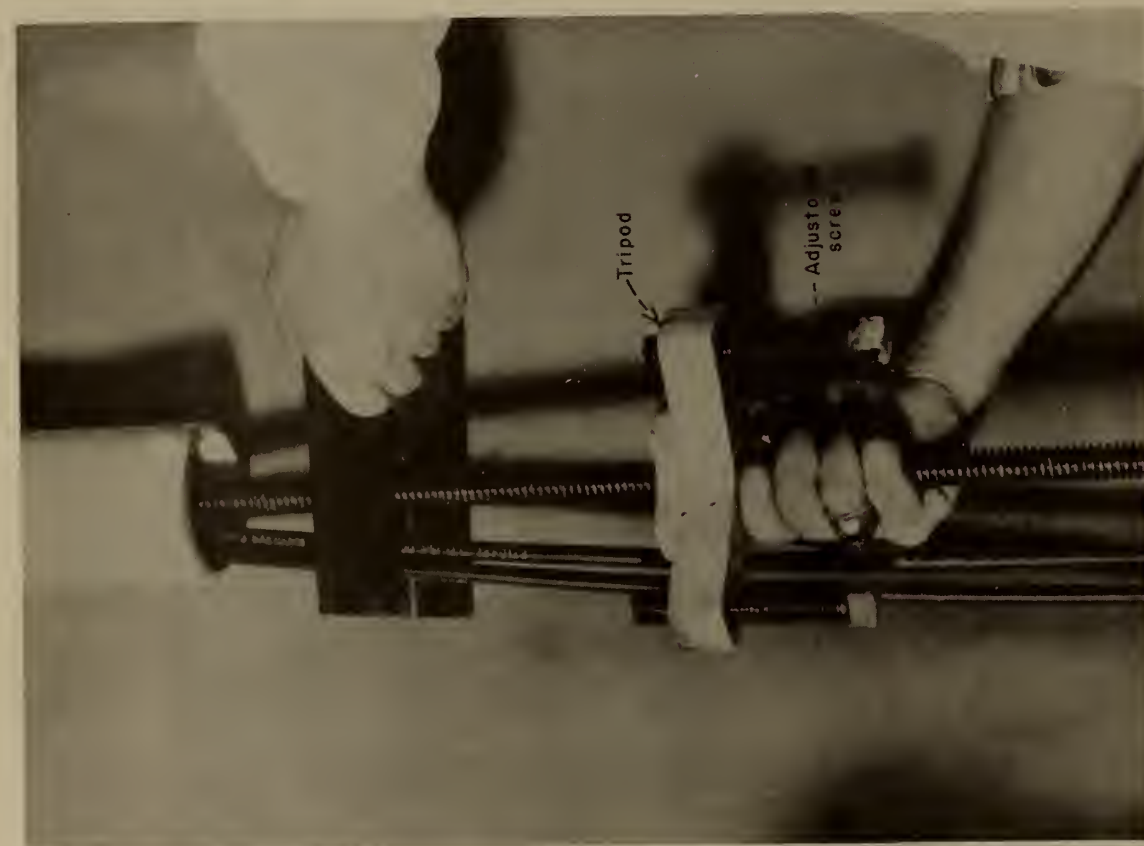


FIGURE 12.—BST assembly, step 8b.

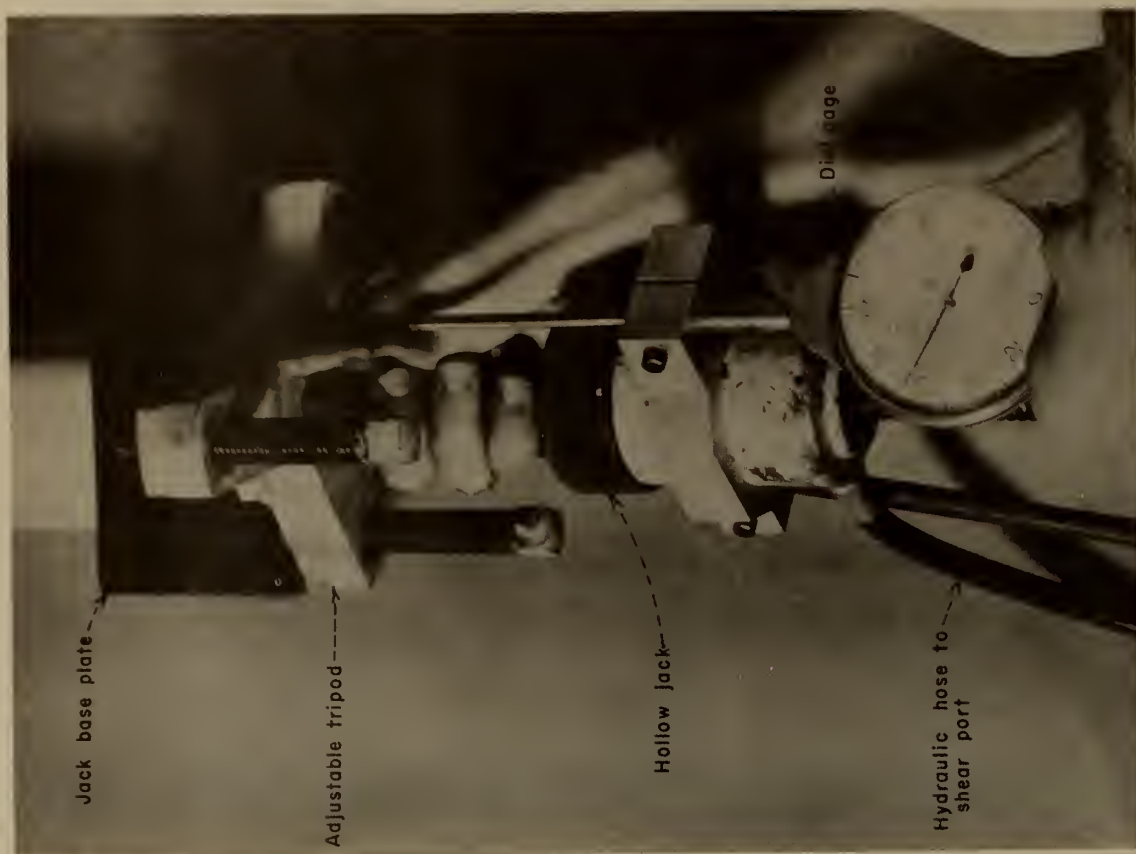


FIGURE 13.—BST assembly, step 8c-1.



FIGURE 14.—BST assembly, step 8c-2.

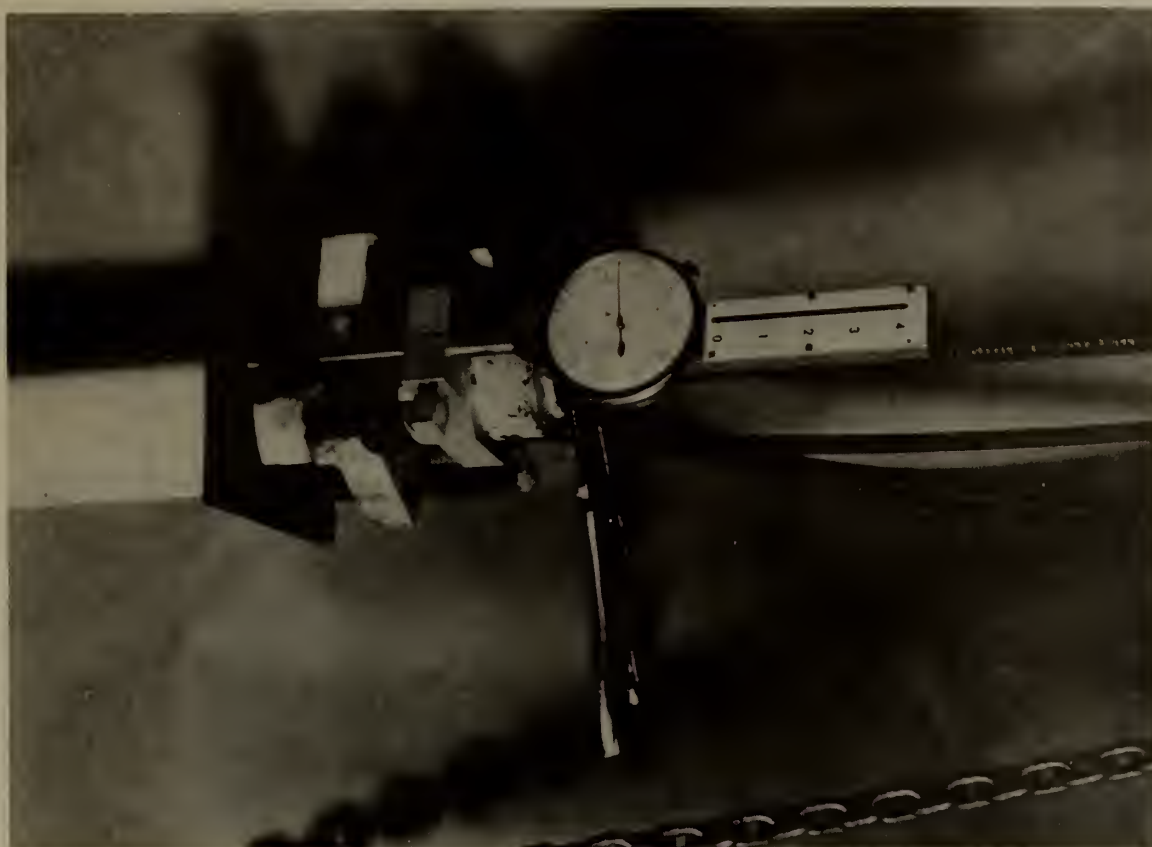


FIGURE 15.—BST assembly, step 8c-3.



FIGURE 17.—BST assembly, step 9.

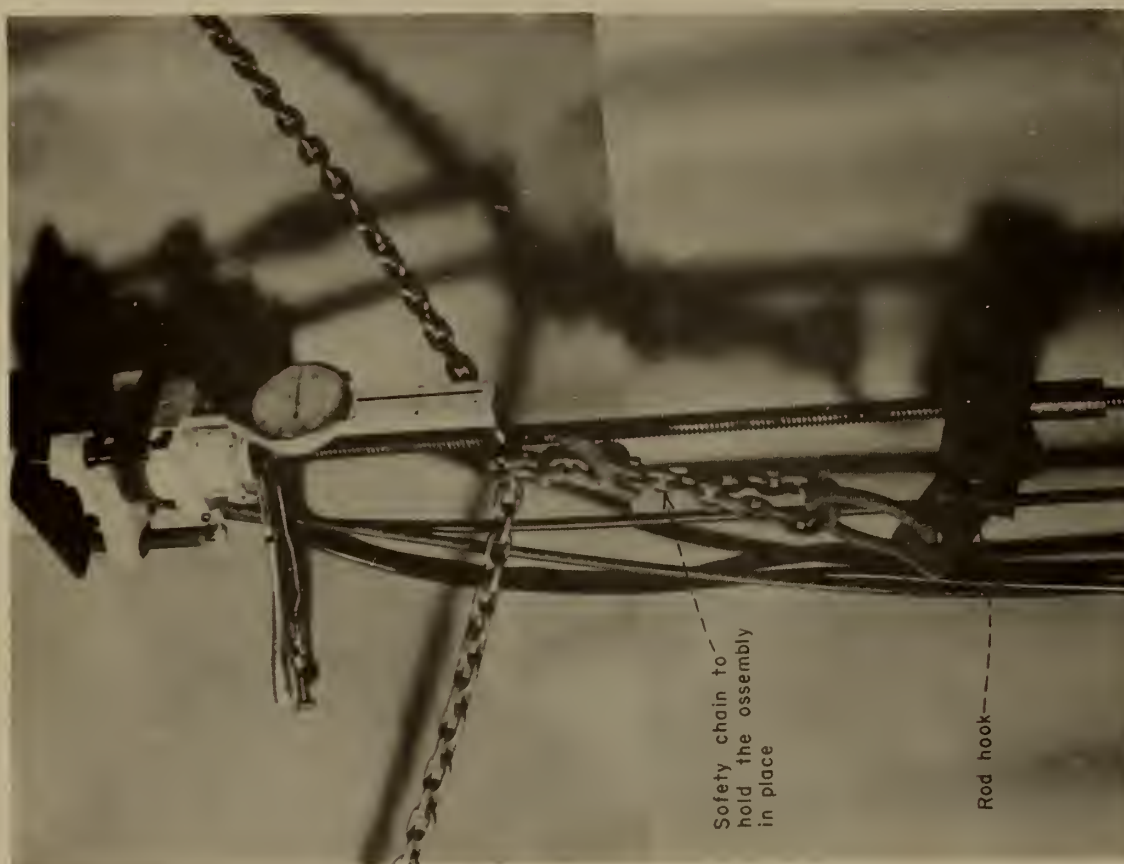


FIGURE 16.—BST assembly, step 8c-4.

TABLE 3.—Completed BST data sheet
DATA SHEET FOR BOREHOLE SHEAR TESTER

Mine	COAL MINE "X", UTAH		Date	OCTOBER 1, 1980	
Type of rock	COAL	Roof	SANDSTONE	Tested by	HARAMY AND DeWAELE
Hole No.	W-25	Hole location	HOLE IN ROOF, CROSSCUT	Floor	
			#25, 3d Rt.	Hole depth	30'(NX-HOLE)

Test	Normal		Shear		Orientation of teeth	Depth* Into hole	Displacement	
	P _n	σ _n	P _s	T _s				
1	1000	2392	1350	1841	NS	12'5" + H**	—	—
2	1250	2990	1700	2318	NS	10'7.5" + H	—	—
			250	ZERO READING ON DIAL GAGE = 6.0			5.95	0.05
			500				5.61	0.39
			750				5.25	0.75
			1000				4.85	1.15
			1250				4.20	1.80
			1500				3.56	2.44
			1700	PEAK			2.43	3.57
3	1500	3588	1760	2400	NS	8'4.5" + H	—	—
			250				5.00	0.00
			500				4.90	0.10
			750	ZERO DISPL. = 5.0			4.79	0.21
			1000				4.44	0.56
			1250				2.77	2.23
			1500				.16	4.84
			1760	PEAK			—	—
4	1750	4186	2200	3000	EW	8'11" + H	—	—
			250				5.80	0.20
			500	ZERO DISP = 6.0			5.27	0.73
			750				5.09	0.91
			1000				4.84	1.16
			1250				4.60	1.40
			1500				4.21	1.79
			1750				3.68	2.32
			2000				2.88	3.12
			2200	PEAK			1.30	4.70
5	2000	4784	2350	3205	EW	11'0" + H	—	—
			500				6.55	0.45
			750	ZERO DISPL. = 7.0			6.14	0.86
			1000				5.72	1.23
			1250				5.40	1.60
			1500				5.09	1.91
			1750				4.70	2.30
5			2000				3.50	3.50
			2250				2.00	5.00
			2350				1.92	4.08
6	2250	5380	3010	4106		12'6" + H	—	—
			500				7.09	0.91
			1000				6.05	1.95
			1500				5.49	2.51
			2000				4.90	3.10
			2500				3.92	4.08
			3000				2.15	
			3010				—	—

*Distance from collar of borehole to the center of loading plates
*H = Length of BST head 1.5'

P_n = Normal gage pressure (psig)
 σ_n = Normal stress (psi) (calculated)

P_s = Maximum shearing gage pressure
 T_s = Shearing stress (psi) (calculated)

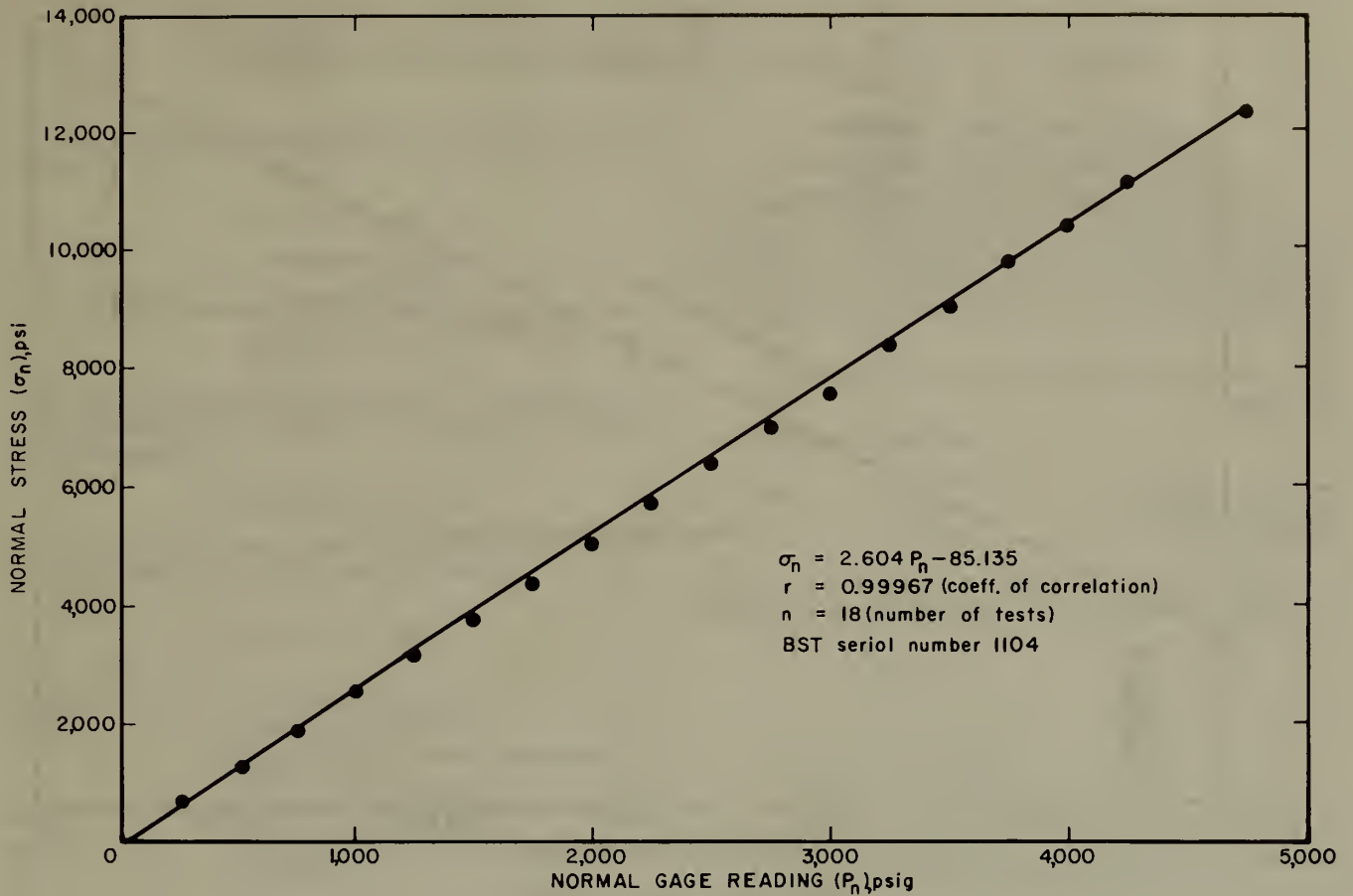


FIGURE 18.—Normal stress calibration curve.

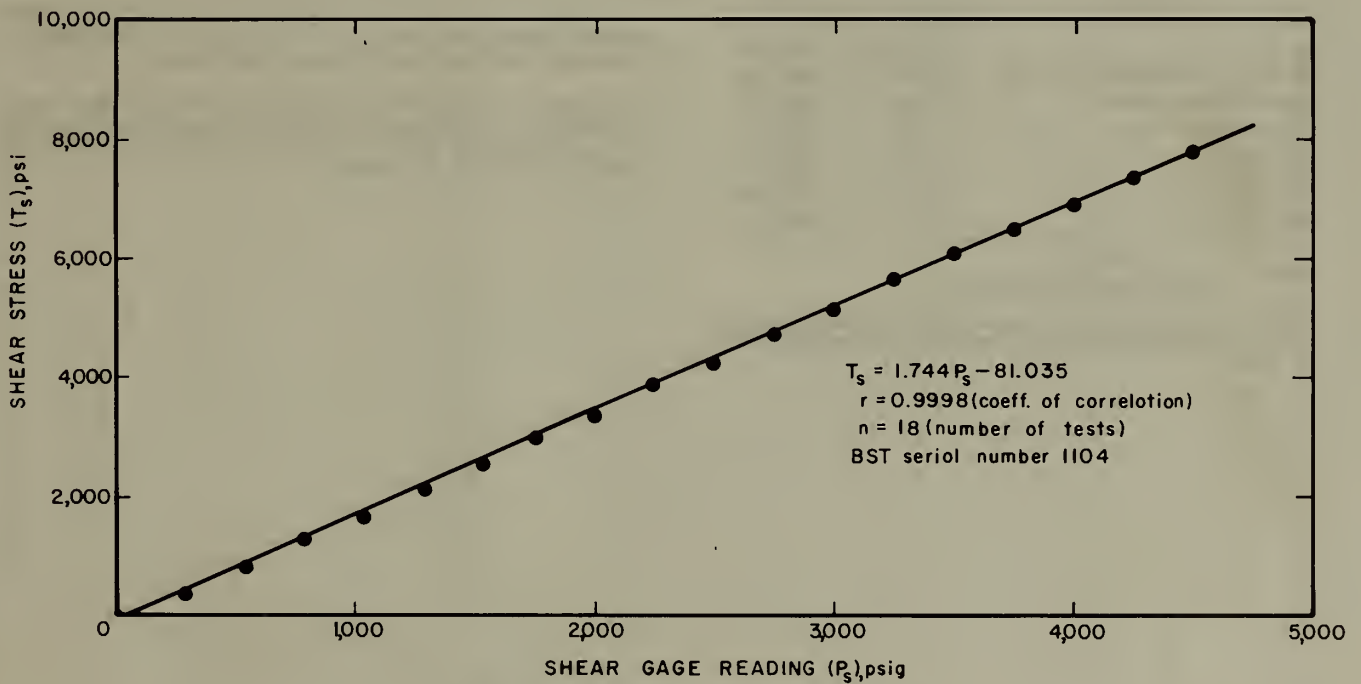


FIGURE 19.—Shear stress calibration curve.

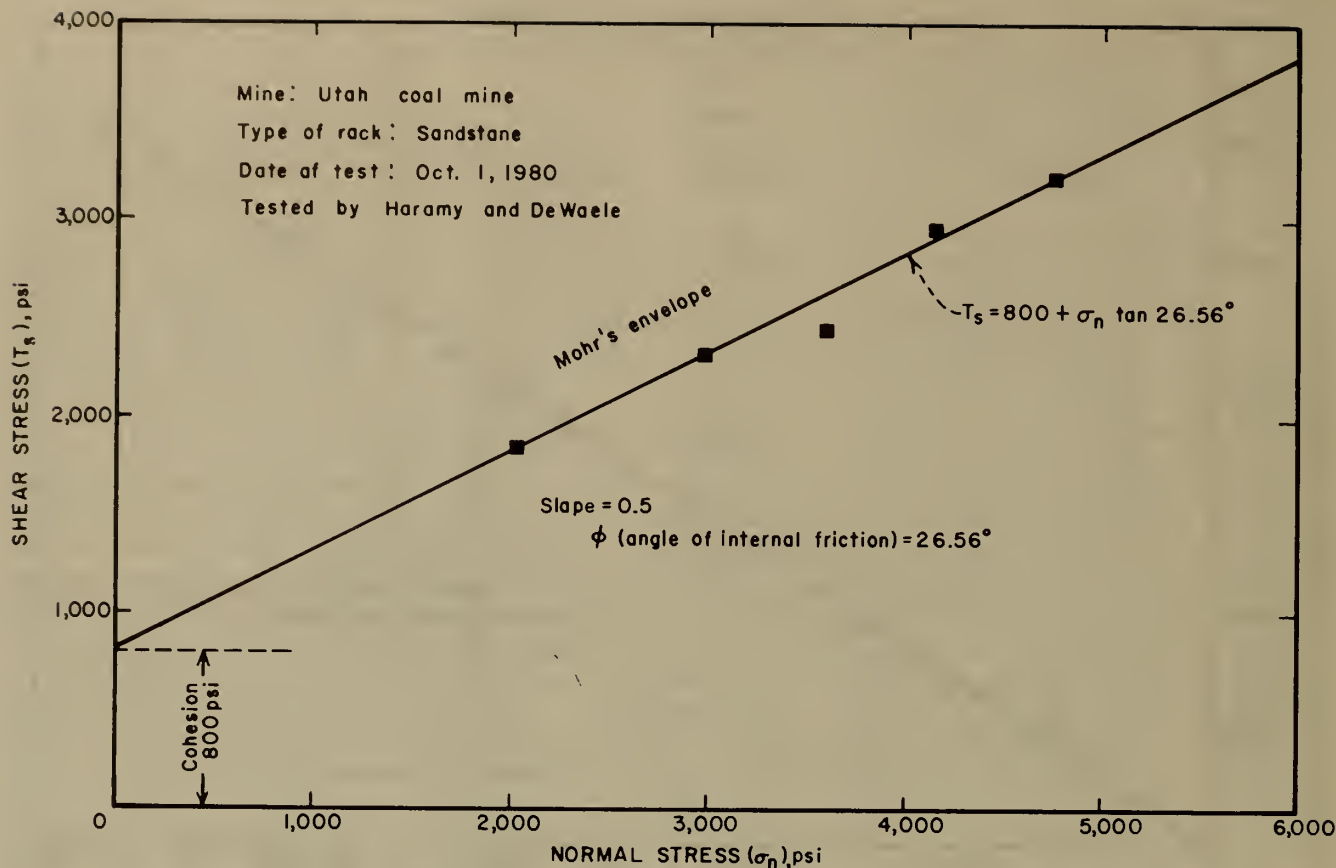


FIGURE 20.—Example of BST plot.

TABLE 4.—Weights of BST components

Component	Weight	Stress ¹
RW rod.....	1.8 lb/ft	0.45 psi/ft
BST body and 2 attached short hoses....	9.5 lb _t	2.375 psi
Hydraulic hoses and fluid.....	0.1 lb/ft	0.025 psi/ft
Tripod and base plate.....	7.0 lb	1.750 psi
Dial gage.....	1.0 lb	0.250 psi
Threaded rods.....	1.5 lb/ft	0.375 psi/ft
Hollow jack.....	11.0 lb	2.750 psi/ft
Half-nut clamp.....	.8 lb	0.200 psi

¹Stress = $\frac{\text{weight}}{2 \text{ (cross-sectional area of plates)}}$

NOTE.—This table also allows the operator to decide whether a winch is needed to hold the BST assembly as apposed to the operator handling the weight.

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APPENDIX—SEATING PRESSURE CALCULATIONS FOR COAL

The coefficient of sliding friction can be calculated as follows:

$$\mu = \tan \beta$$

where μ = coefficient of friction

and β = angle of friction between the shear plates and the material being tested.

In laboratory testing by the Bureau, the coefficient of friction between coal and steel was found to be 0.3 ± 0.04 . From equation 1

$$\beta = \arctan(0.3) = 16.7^\circ$$

The minimum normal stress to cause material failure can be calculated using the following formula:

$$\frac{C_o}{\sigma_n} < \tan(\theta + \beta) - \tan \phi$$

where C_o = materials cohesion,
 σ_n = normal stress,
 θ = angle of plate inclination shown in figure A-1,
 β = angle of friction between steel plates and rock tested,
 and ϕ = angle of internal friction of the material.

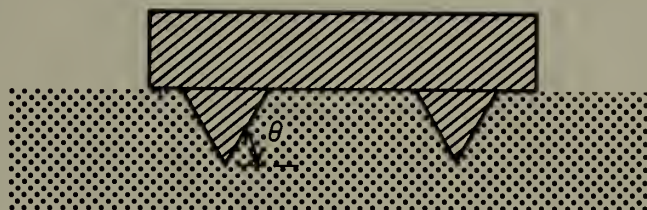


FIGURE A-1.—Angle of plate inclination.

Substituting in equation 2

$$\begin{array}{ll} \theta = 60^\circ & \text{Fixed,} \\ \phi = 60^\circ & \text{Highest for coal,} \\ \text{and } \beta = 16.7^\circ & \text{from equation 1} \end{array}$$

Thus, for coal with $C_o = 1,000$ psi, the minimum σ_n to cause material failure rather than slippage is

$$\begin{aligned} \frac{C_o}{\sigma_n} &< 2.5 \\ \sigma_n &> \frac{1,000}{2.5} > 400 \text{ psi.} \end{aligned}$$

The normal stress will vary depending on C_o and μ of coal. This method of estimating σ_n is a good approximation and may be used for any type of rock.

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